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CONTROLLED THERMONUCLEAR RESEARCH IN THE USSR

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PREFACE

The promise of an unlimited source of power is most inviting. This is especially true in the light of limited reserves of conventional fuels, such as coal, gas, and oil. The United States, Great Britain, and the Soviet Union are expending considerable effort in attempting to solve the problem of a new power source by engaging in research on controlled thermonuclear reactions. Of the two primary types of nuclear reactions — fusion and fission, the fusion reaction or controlled thermonuclear reaction offers the greatest possibility of a continuing supply of power. Several other countries, notably Sweden, West Germany, France, and Japan are also investigating this problem, but on a lesser scale. To the nation, or bloc of nations, first accomplishing the control and utilization of thermonuclear reactions will accrue a considerable rise in prestige in addition to economic, technical, and possibly military advantages.

There are many reasons justifying these efforts; some of the more important are:

1. Fusion reactors utilizing deuterium (or possibly a mixture of deuterium and tritium) as fuel would provide practically an inexhaustible source of power.

2. The radioactive-waste disposal problem would be practically nonexistent in a fusion reactor. Only the induced radioactivity in the structural materials would be present after a fusion reactor shuts down.

3. The expensive and time-consuming fabrication and reprocessing of the fission reactor fuels would be eliminated.

4. The safety factor of a fusion reactor should be greater than that of a fission reactor. The danger of an accident resulting in widespread radioactive contamination would be virtually nonexistent.

5. Ultimately fusion reactors may function with greater efficiency than fission reactors due to the possibility of direct conversion of a portion of the nuclear energy to electrical energy.

6. A fusion reactor would provide a practically inexhaustible source of neutrons for use in research, production of isotopes, and for production of fissionable materials for power generation and other uses.

This general survey of the controlled thermonuclear research program of the USSR was undertaken in view of Soviet advances in this field, especially those reported at the Second International Conference on the Peaceful Uses of Atomic Energy, September 1958, Geneva. A partial list of the scientific personnel associated with the Soviet controlled fusion research program is presented as appendix A. All persons named therein have authored or co-authored scientific reports concerning theoretical or experimental research related to controlled fusion research or have been specifically identified by such authors as participating in the research. A bibliography of pertinent papers is included as appendix B. All material available as of 1 June 1959 was used in preparation of both lists mentioned.

The cutoff date of the information used during the preparation of this report is June 1959.

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CONTROLLED THERMONUCLEAR RESEARCH IN THE USSR

PROBLEM

To assess Soviet capabilities in controlled thermonuclear research.

CONCLUSIONS

1. The USSR has a well established controlled thermonuclear research program believed to be comparable in size and pattern of research with the U.S. program. Soviet controlled thermonuclear research encompasses at least six major research centers and deals with experimentation utilizing a number of fusion reaction techniques, including "pinch," magnetic mirror, and ion injection.

2. Although the production of controlled thermonuclear energy has not been attained in the USSR, it is estimated that the Soviet Union could produce thermonuclear power (on a laboratory scale) as soon as any of the Western countries. Perhaps thermonuclear power can be produced on a small scale within the next few years, but it will be many more years before a fusion reactor capable of producing economically competitive power can be achieved.

SUMMARY

Soviet research into CTR proceeded under tight security until April 1956 when Igor' V. Kurchatov, the director of the Institute of Atomic Energy, Moscow, presented a paper at Harwell, England, on the possibility of controlling thermonuclear reactions.

The Kurchatov paper presented data obtained from a series of Soviet fusion experiments involving high-current gaseous discharges. The data evidenced the attainment of a temperature of approximately one million degrees and a resulting production of neutrons. However, Kurchatov made no specific claim that the neutrons detected were of thermonuclear origin. *

Western scientists, competent in controlled fusion research, agreed that the technological level of the described experiments indicated a research effort in controlled fusion in the Soviet Union comparable with any similar effort in the West.

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* Thermonuclear reactions are fusion reactions occurring under conditions in which the reacting nuclei are at high temperature (i.e., possess appreciable kinetic energy and collide while moving about more or less randomly).

Technical presentations and conversational remarks by Soviet scientists attending the 3rd International Conference on Ionization Phenomena in Gases (the Venice Conference) in June 1957 seemed to indicate that the Soviets may not have understood fully the concept of plasma * stability. Nevertheless, analyses of later papers proved this assumption to be untrue.

Papers presented at the Second International Conference on the Peaceful Uses of Atomic Energy, September 1958, Geneva (Geneva II) indicated that the Soviets had a sound understanding of most of the theoretical problems involved, as well as a competent experimental research program to test their theoretical concepts. Data presented in the Soviet papers agreed, in most instances, with that obtained in the West; and in a few instances, especially with regard to certain kinds of radiation losses, the Soviet theoretical treatment was more complete.

A survey of the information obtained from Geneva II shows that the Soviets have fusion research programs corresponding to most Western programs. Although the basic design of at least one machine (ALPHA) was essentially copied from a Western version (the UK's ZETA), Soviet ability to assimilate Western disclosures, together with their own native ingenuity and talent, permitted them to construct similar machines with many of their own innovations.

Most of the information available on the Soviet controlled thermonuclear research program concerns work conducted at the Institute of Atomic Energy (IAE), Moscow. Other CTR experimental groups have been working at Leningrad, Khar'kov, and Sukhumi. Each experimental group apparently has adequate theoretical support to back-stop a significant experimental program.

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* Plasma — a fully ionized gas, no longer composed of electrically neutral atoms or molecules but made up of electrically charged particles: positive nuclei and negative electrons. The orbital electrons are dislodged from their orbits, thus creating the plasma.

DISCUSSION

THE TECHNICAL PROBLEM

Nuclear fission is a process whereby a heavy nucleus [e.g., U–235] splits into several parts, the total mass of which is less than the mass of the original nucleus. Nuclear fusion, on the other hand, is the process whereby two light nuclei combine to form a heavier nucleus, the mass of which is less than the total mass of the combining nuclei. In each case, the mass which apparently disappears is actually converted into energy, according to the Einsteinian equation $E = mc^2$ or $\Delta E = \Delta mc^2$; where Δ is the difference, E = energy, m = mass, and c = velocity of light.

The fusion reaction of greatest practical interest is that involving nuclei of deuterium (D, an isotope of hydrogen) with release of energy and formation of tritium (T, another isotope of hydrogen) or helium-3 (He^3).

1) $D+D \rightarrow T+p+E$ (p . . . proton)
(E . . . energy)
2) $D+D \rightarrow He^3+n+E$ (n . . . neutron)

The two reactions proceed with about equal probability. Further reactions can occur, such as:

3) $T+D \rightarrow He^4$ (normal helium) $+n+E$ and
4) $He^3+D \rightarrow He^4+p+E$

The probability for reaction 4) taking place is relatively low.

Although in principle a fusion reaction may seem simple, it must be remembered that this reaction must be induced under conditions of (a) high temperature, (b) randomized motion, and (c) confinement. In a proper sense, no temperature exists without reasonable randomization. These conditions may be explained as follows:

Temperature

Temperature is a measure of the energy of the deuterons and is directly proportional to the square of their average velocity. Theoretically, a temperature of about 400,000,000 degrees centigrade is necessary to ignite a fusion reaction in deuterium. This is equivalent to approximately 35,000 electron volts, since one electron volt corresponds to a temperature of about 11,600 degrees centigrade.

The extremely high energies (temperature) needed in thermonuclear research can be imparted to the plasma by several different methods. One such method involves the direct application of an electric field to the plasma. The field accelerates the charged particles of the plasma, particularly the electrons, thus increasing their energy. This method is called "resistive" or "ohmic heating" and the degree of heating is directly proportional to the square of the current passing through the plasma (I^2) and to the electrical resistance (R) of the plasma. Because of the plasma's negative temperature coefficient of resistance, there is a limit to the amount of heating that can be accomplished in this manner. Other heating methods utilize electric fields in more subtle ways; some are capable of heating the ions preferentially. The extreme case occurs for energetic ion injection.

Randomizing

Because particles moving with identical velocities (equal speed and same direction) have a very low collision probability and thus a very low fusion probability, their velocities must be randomized in order to increase these probabilities and enhance the chances for fusion.

Confinement

Because a plasma tends to expand upon heating it must be contained at least long enough to allow a significant fraction of the fusionable fuel to react. For example, an initial plasma density of one ten-thousandth of that of normal atmospheric density will, at the fusion temperature, exert a pressure of approximately 100 atmospheres (1500 lbs/sq. in.). Long confinement times are necessitated by the extremely long mean-free-path lengths of nuclei in a low density plasma. Material walls cannot be used because hot particles striking the wall would lose their energy and thus cool the plasma. Also, impurities from the container walls would be introduced into the plasma.

All of the known promising methods for plasma confinement utilize magnetic fields. These confining fields may be produced externally by wound coils or internally by currents passing through the plasma itself. An externally produced magnetic field of 50,000 gauss can, in principle, contain a particle pressure of 100 atmospheres.

To date, no data obtained by scientists, either Western or Soviet, indicate the absolute unattainability of these conditions of temperature, randomization, and confinement.

BACKGROUND ON SOVIET CTR RESEARCH

The Soviet controlled thermonuclear research proceeded under the wraps of total security from the time of its inception until 26 April 1956. At that time, Igor' V. Kurchatov gave a paper at Harwell, England, on the possibility of controlled fusion reaction. That paper was a report on some Soviet experiments in controlled fusion research that had been conducted by L. A. Artsimovich and M. A. Leontovich at the Institute of Atomic Energy (IAE), Moscow. Kurchatov is the director of that institute and was merely reporting the results of research conducted by scientists working under him.

The experiments on which Kurchatov reported were based on high-current gaseous discharges in a linear geometry. The data indicated that a temperature of approximately one million degrees centigrade had been obtained and an emission of neutrons detected. Kurchatov made no claim of a thermonuclear origin for these neutrons.

In the late summer of 1956, in Stockholm, Sweden, L. A. Artsimovich presented a technical paper in which he covered in detail the experiment that had been previously covered in only a cursory manner by Kurchatov.

Many articles on fusion research appeared in Soviet technical journals after the initial release of information by Kurchatov. Most of the articles were either directly applicable or peripheral to Artsimovich's studies. These Soviet papers constituted almost the whole of the world-wide fusion research information released up to June 1957.

The first important public release of Western fusion information was made at the Third International Conference on Ionization Phenomena in Gases, 11–15 June 1957, Venice, Italy (Venice Conference). Although the Soviets attended this conference, it was apparent that they were more interested in receiving than in giving information.

Between June 1957 and the Second International Conference on Peaceful Uses of Atomic Energy, September 1958, Geneva (Geneva II), the Soviet journals continued to publish many reports of fusion research; but these too were related to the earlier work of Artsimovich.

When the joint U.S.–U.K. announcements concerning controlled thermonuclear research were made on 24 January 1958, Kurchatov made some further statements which indicated that additional Soviet advances had been made since his initial report in April 1956.[4]

The fusion research papers to be presented by Soviets attending Geneva II, were submitted at the latest possible moment. It is unkown whether this was a matter of last minute preparations or merely a matter of their waiting to see what the West would release. It is quite possible that the joint U.S.–U.K. action in declassifying fusion research caught the Soviets by surprise.

The Soviet fusion papers presented at Geneva II were good but contained little of outstanding importance or newness to the West. One exception was their theoretical report on radiation losses.

Four-volume sets of books composed of approximately one hundred papers covering fusion research at the Institute of Atomic Energy, Moscow (IAE) during the period of 1951 to 1958 were distributed as presentation sets to delegates attending Geneva II. The papers are very thorough and are indicative of a somewhat higher level of achievement and competence than had originally been attributed to the scientists in the Soviet controlled fusion research program. The contents of these four volumes comprise the sum total of our knowledge to date on the technical aspects of the Soviet CTR program.

APPROACHES

There are numerous possible approaches to the attainment of controlled thermonuclear reactions. All of the known approaches involve the use of a plasma, heated and confined, to induce the fusion reactions. The approaches differ in the methods used for the production, heating, and confinement of the plasmas. The Soviets appear to be actively investigating the known major approaches (i.e. "pinch," magnetic mirror, and "stellarator") and several minor approaches.

Pinch Approach

The electromagnetic phenomenon commonly referred to as the "pinch effect" has been known to scientists for many years but has been studied as a possible approach to controlled thermonuclear reactions only since 1951. In the pinch approach, initial plasma confinement is achieved by magnetic fields resulting from a current flow within the plasma itself. The plasma is heated by the combined effect of magnetic compression by the confining field and resistive heating due to the flow of current within the plasma. The amount of resistive heating is limited by the negative temperature coefficient of resistance of the plasma and the confinement time is in part limited by the duration of the rise of the current through the plasma.

Although there are inherent instabilities in the pinch, a greater degree of stability can be obtained by the superimposition of a weak externally applied longitudinal magnetic field. Despite these instabilities, the pinch approach has continued to appeal because of its simplicity, both in theory and in equipment required.

The Soviets apparently recognized the problem of plasma instabilities at an early date. As early as 1952, M. A. Leontovich and V. D. Shafranov made theoretical studies of the

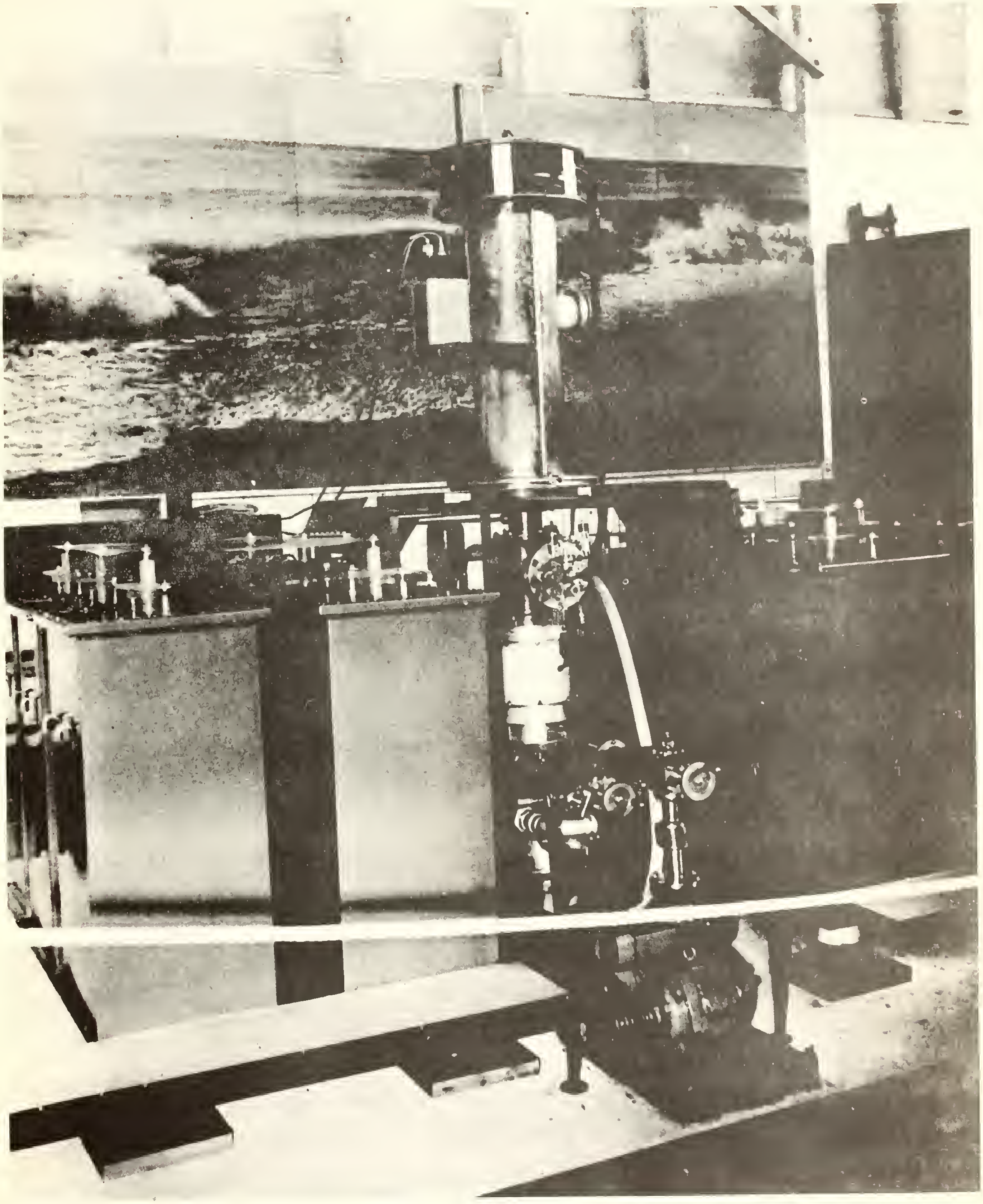


FIGURE 1. Soviet straight tube discharge apparatus. (Equipment used in the experiments described by Kurchatov at Harwell, England, April 1956.)

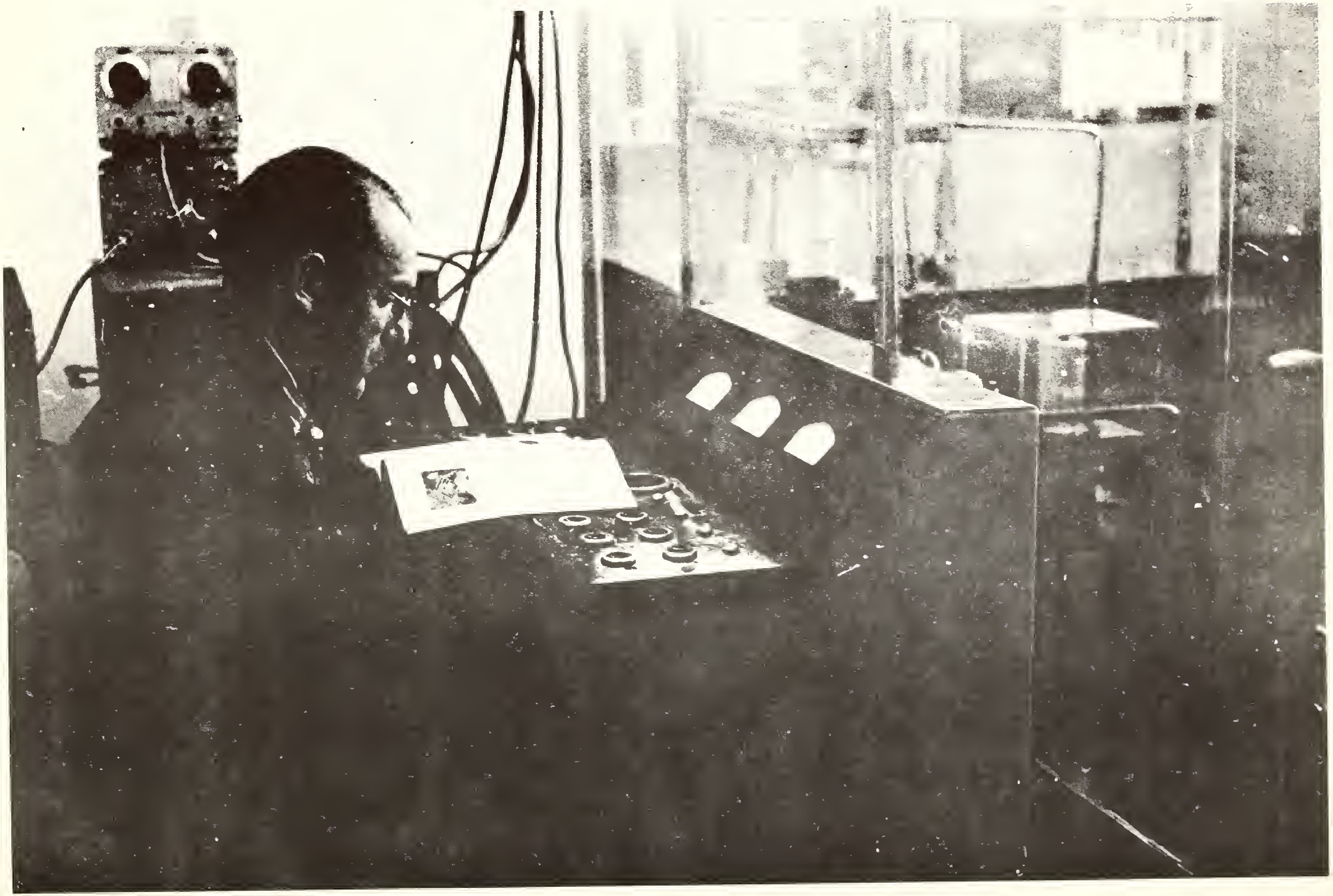


FIGURE 2. Control panel for discharge apparatus shown in figure 1.

stabilizing effect of an externally applied longitudinal magnetic field. Also in 1952, B. A. Trubnikov, under the direction of Leontovich, made additional studies of the instabilities of a plasma. These earlier works on plasma stability were followed by later research by V. D. Shafranov, T. F. Volkov, S. I. Braginskiy, and B. B. Kadomtsev; D. V. Orlinskiy, L. I. Rudakov, and R. Z. Sagdeyev.

Pinch experiments may be carried out in either linear (cylindrical)) or toroidal (doughnut-shaped) tubes. The Soviets have used both geometries.

The pinch experiments discussed by I. V. Kurchatov in his 1956 speech at Harwell, England, were in a linear geometry. These experiments were conducted at the Institute of Atomic Energy, Moscow, by a research team directed by L. A. Artsimovich with theoretical support supplied by a team of theoreticians directed by M. A. Leontovich. This work was actually carried out about 1953, but the initial theoretical studies were carried out in 1951 by I. Ye. Tamm and A. D. Sakharov.

In addition to the linear geometry pinch experiments, the Soviets also conducted considerable research wherein a toroidal geometry was employed. The best known of these experiments is the one with ALPHA (almost a replica of the British ZETA). This experiment was initiated in early 1958 at an institute in Leningrad, probably the Institute of Electro-Physical Apparatus. Earlier work on toroidal geometry pinch experiments was conducted at the Institute of Atomic Energy, Moscow, and has been reported by A. M. Andrianov, 1951; G. I. Budker, 1951; B. I. Davydov, 1951; N. M. Poliyevktov-Nikoladze, 1958, and others.

The Soviets, realizing the limitations inherent in ohmic heating of plasmas, conducted considerable research on other methods of heating. As early as 1951, G. I. Budker proposed a method of heating a plasma by increasing magnetic fields. In 1956, L. I. Rudakov and R. Z. Sagdeyev conducted research on heating plasmas by use of high frequencies.

In the course of the pinch experiments, many diagnostic techniques were developed for determining the characteristics and behavior of the plasma. Some early spectroscopic diagnostic research was reported in 1947 by S. E. Frish and Yu. M. Kagan. In 1951 G. I. Budker reported some work on particle drift in toroidal discharge. In 1952, A. I. Akhiyezer and R. V. Polovin published a report concerning plasma behavior in a combined electric and magnetic field. Additional diagnostic research pertaining to plasma behavior and characteristics was carried out during the period 1951–58. The latest plasma diagnostic research reported by the Soviets was contained in certain reports presented at Geneva II. K. D. Sinel'nikov reported on some electron resonance and wave guide properties of plasmas, and S. Yu. Luk'yanov and V. I. Sinitsyn reported the results of some of the latest spectroscopic research on high-temperature plasmas.

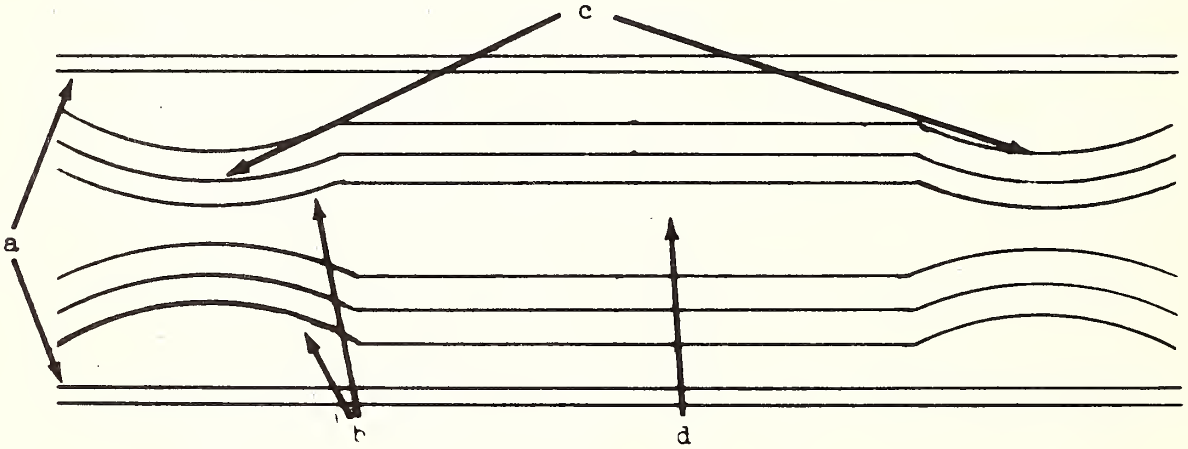
One phase of controlled fusion research in which the Soviets have excelled, in some instances surpassing the work of Western scientists, is the study of radiation losses from a plasma. The results of one aspect of this research, a theoretical treatment of electron synchrotron radiation reported at Geneva II by B. A. Trubnikov and V. S. Kudryavtsev, indicate that the Soviets have gone further in this study than Western scientists. That report concerned itself with electromagnetic radiation interactions with plasma and considered radiation losses at higher harmonics of the electron cyclotron resonance frequency. This particular development was new to Western scientists. Earlier work on radiation research was conducted by a group led by A. M. Andrianov. Some of the later work conducted at the Institute of Atomic Energy between 1951 and 1958 is reported in the Soviet Geneva II presentation set.

An overall analysis of available information indicates that the Soviets are actively investigating the many phases of pinch research, even though they may not feel that this approach will lead to the ultimate solution of the problem of controlled fusion.

Magnetic Mirror Approach

The tendency for charged particles moving in a nonuniform magnetic field to be repelled from regions where the magnetic field is strongest has been known for a great many years. This general principle has been used as a basis for a method of plasma confinement, and is designated as the "magnetic mirror approach."

A magnetic mirror machine in its simplest form consists of a straight tube with external coils which provide a variable magnetic field within the tube. The coils are so arranged that in the center of the tube, the magnetic lines of force are parallel to the axis, while at the ends the magnetic field strength is increased, thus bringing the lines of force closer together. These end areas of increased magnetic field strength are referred to as the magnetic mirrors. This is illustrated in the accompanying diagram.



a - Cylinder walls
b - Lines of force
c - Magnetic mirror
d - Area of confinement

Charged particles approaching the magnetic mirror region (c) are reflected back into the area of confinement (d). Only partial confinement is provided but it does permit the use of cylindrically shaped vacuum chambers.

In a mirror machine, the moving particles are selectively retained, those with a relatively high component of velocity at right angles to the magnetic lines of force being retained longer than those directed along the lines of force.

To date, no instabilities have been observed in mirror research but the behavior at the required higher densities and temperatures remain to be studied. The plasma may be heated by magnetic compression, accomplished by either increasing the magnetic field strength throughout or by causing the mirror regions to move inward. Alternatively, hot plasmas can be obtained through injection of fairly energetic ions, a technique not readily possible in pinch research.

Although the Soviet papers presented at Geneva II contained little information pertaining to mirror research, the Soviet Geneva II presentation set did report further on such research. G. I. Budker reported some work of this type in 1954 wherein he discussed the magnetic mirror geometry and the possibility of direct conversion of the nuclear energy to electrical energy. In 1957 a group under the direction of G. M. Antropov conducted research pertaining to the behavior of electrons in a magnetic mirror machine. A bit earlier (1956) O. B. Firsov reported studies of the repulsion of charged particles from regions of a strong magnetic field. Other work was reported in additional articles in the same compilation.

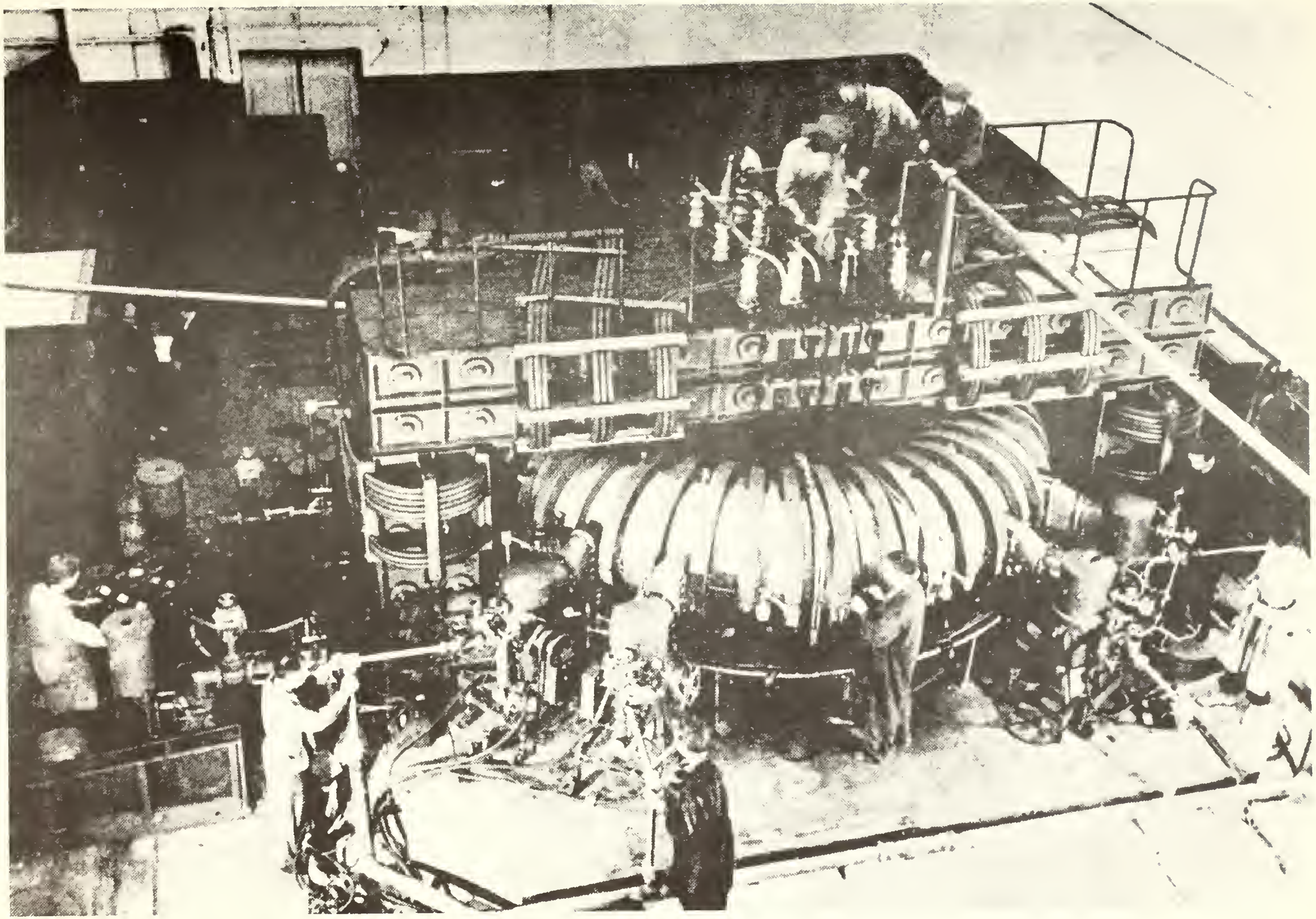


FIGURE 3. Soviet toroidal discharge apparatus (Alpha).

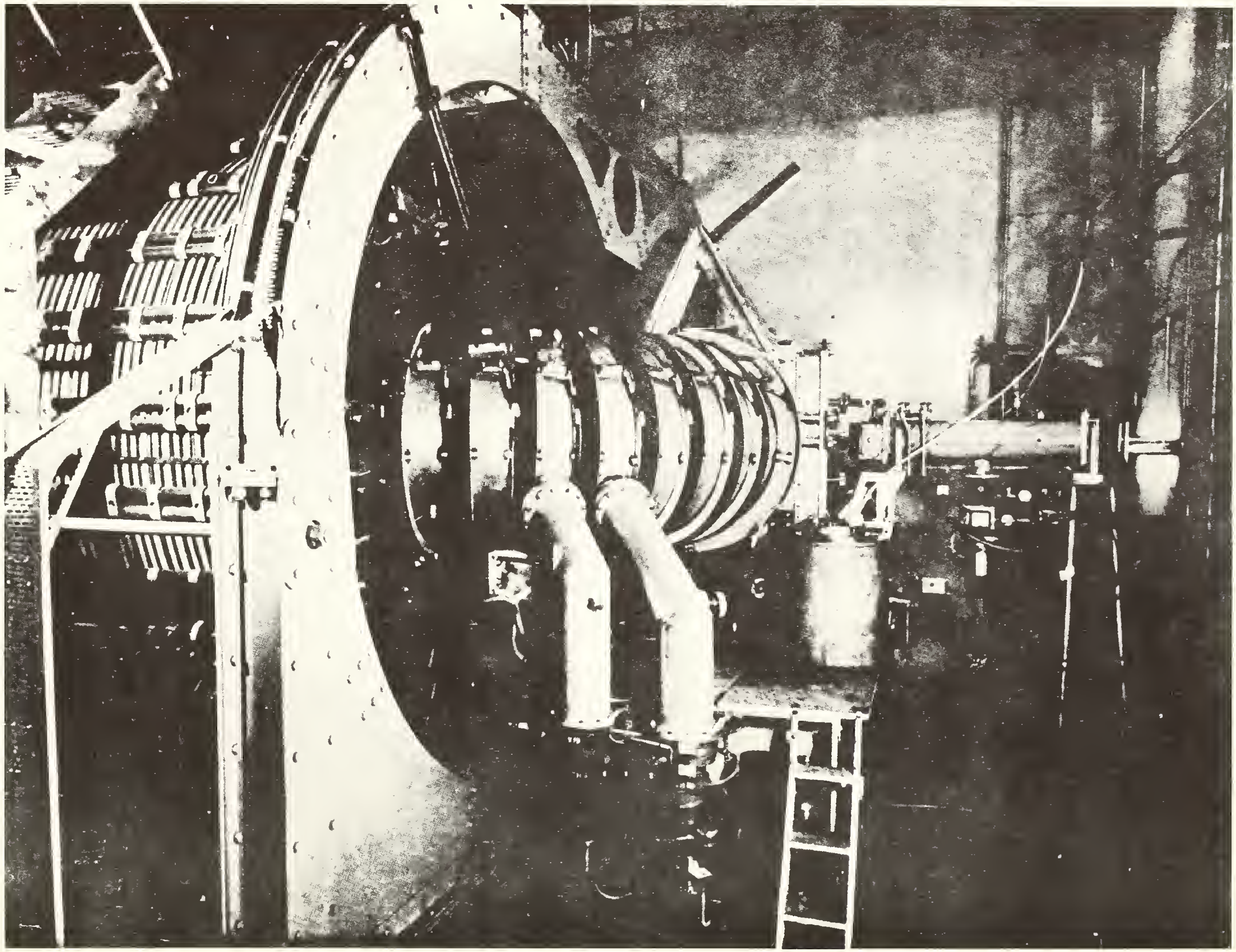


FIGURE 4. A British toroidal discharge apparatus (ZETA). (Note similarity between this machine and the Soviet Alpha shown in figure 3.)

In August 1958, just prior to the opening of Geneva II, the Soviets announced their large magnetic mirror experimental machine OGRA, into which they planned to inject energetic molecular beams. This machine had a vacuum chamber some 20 meters (~ 65 ft) in length and 1.4 meters (~ 5 ft) in diameter. It is located at the Institute of Atomic Energy, Moscow, and is under the direction of Igor' Nikolayevich Golovin. At the time of the announcement, the machine had not been put into operation. In October 1958, Western scientists visiting the IAE reported that the Soviets were having difficulty with the vacuum system on OGRA. These scientists also reported the existence of a smaller prototype of OGRA, called OGRINA, also located at the IAE. Satisfactory results have not been obtained from OGRINA due to difficulties encountered in injecting an energetic beam of particles into the machine.

The experiment in OGRA depended upon a collision process for plasma formation. This differs from similar experiments in the West in that the Western experiments (the DCX at Oak Ridge) utilize an electric arc in a vacuum to achieve the dissociation of injected molecular ions to form a plasma. Soviet scientists are now thought to be considering an arc breakup mechanism as a future modification of OGRA.

There is no doubt that the Soviets were working on OGRA prior to May 1958. Nevertheless, it is believed that they utilized considerable information from the papers concerning similar research (at Oak Ridge, Tennessee), presented at the American Physical Society meeting held in Washington, D. C., in May 1958. The short time between May and August probably could not have permitted incorporation of the vacuum arc modifications in the design of OGRA.

There is no evidence of Soviet magnetic mirror research at any institute other than the Institute of Atomic Energy, Moscow.

Stellarator Approach

The word "stellarator" was coined in the United States to indicate a particular class of devices in which it is hoped that stellar temperatures can be generated. These are devices in which ionized gas or plasma is confined in a generally toroidal tube by means of a very strong external magnetic field.

Charged particles, when in a magnetic field, execute tight spirals around the lines of force. These particles can be kept from the wall of a tube through the establishment of a very strong longitudinal magnetic field. Even though the longitudinal field will inhibit the flow of the particles to the wall, it will not affect the drift along the line of force. Therefore, if the tube were straight, the particles would escape through the end of the tube. The problem of end losses can be eliminated by bending the vacuum chamber into a torus (doughnut shape), thus making the lines of force circular. However, since the magnetic field intensity is not uniform over the cross section of the tube, there is an additional particle drift toward the walls — positive ions in one direction and electrons in the other. This separation of charges produces an electric field, which in combination with the magnetic field, pushes all particles toward the outer wall. It was found that if the torus were twisted into a figure eight, the electromagnetic drift toward the wall could be prevented. Later research showed that the same effect could be produced by proper application of magnetic fields, thus eliminating the figure-eight geometry.

In current research, the plasma within a stellarator is heated in two steps. Ohmic heating, by means of a current induced in the plasma, is used to heat the plasma to approximately one million degrees. Beyond this point, a system of "magnetic pumping" is used to further increase the temperature. This system involves the use of a rapidly pulsating magnetic field in one section of the tube. This field is pulsed at radio frequencies (millions of cycles per second) and the alternate compression and expansion of the plasma actually adds energy, thus increasing the temperature. It is hoped that the temperature of 100 million degrees needed can be attained in this manner.

The Soviets have published little, if any, information on their stellarator program, yet it is known that such a program exists.

R. A. Demirkhanov, while attending the 3rd International Conference on Ionization Phenomena in Gases, Venice, Italy, 11–15 June 1957, showed considerable interest in a paper presented by A. Schlüter, a German scientist. This paper presented the essence of the theory of magnetic pumping already developed in the West. At the time of the meeting, the Soviet scientists said they had not tried this method of heating a plasma but would try it upon their return. Since then, various reports have indicated Soviet research in the use of high frequency for heating plasmas. R. Z. Sagdeyev and V. D. Shafranov report research on the plasma absorption of high frequency electromagnetic field energy. B. A. Trubnikov did some theoretical research in 1957–58 in which he investigated the behavior of plasma in a rapidly varying magnetic field.

Western scientists attending the Venice Conference, June 1957, considered Demirkhanov's actions and interests indicative of Soviet research involving techniques similar to those used in the Western stellarator project. Discussions with Demirkhanov at Geneva II confirmed these opinions. He indicated at the time that he was engaged in stellarator type research at an institute in the vicinity of Sukhumi. A Geneva II report by L. A. Artsimovich confirmed the existence of such a research group. He did not actually identify the type research but did identify the institute as the Sukhumi Institute of Electronic Physics and stated that fusion research was being conducted there.

Although each research institute is considered to have adequate theoretical support within itself, it is probable that a lot of the theoretical support for the stellarator type research being conducted at Sukhumi is actually provided by the theoretical group at IAE.

There is insufficient information available to permit a determination of the actual status of stellarator research within the Soviet Union, but it is logical to assume that their program is firmly based since they do have access to all the published material pertaining to this type research in the West.

Other Approaches

Although the major efforts in controlled fusion research involve one or more of the three approaches listed above, there is a minor effort in other studies. In all of these minor research projects, plasma heating processes form the basis for the research.

The Soviets have conducted considerable research in the field of general magnetohydrodynamics. In 1951, V. L. Ginzburg reported on research on magnetohydrodynamic waves in gases. In 1957, I. M. Khalatnikov published the results of recent research on magnetohydrodynamic waves in relativistic hydrodynamics. The latest research in this area was reported by S. I. Braginskiy and A. P. Kazantsev in their study of magnetohydrodynamic waves in a dilute plasma.

The Soviets have studied the heating of plasmas by shock-wave impact. Early research in this area was conducted in 1956 by T. F. Volkov. In 1957, Yu. P. Rayzer and V. D. Shafranov studied the structure of shock waves in plasmas. The extent of Soviet success in this field in unknown; but, to date, no known Western research has succeeded in producing temperatures that even approach those needed in fusion reactions.

Soviet scientists have investigated the possibility of attaining fusion temperatures by electrically exploding fine wires in a vacuum. The results of research in this area were published by V. V. Bondarenko and S. V. Lebedev. Western experiments of the same nature have failed to produce the desired temperatures. Apparently, the Soviet efforts have proven no more successful than those of the West and this particular program has been de-emphasized, if not completely abandoned.

To date, none of these minor approaches have shown sufficient promise to warrant a major study. However, future developments in some phases of this work could necessitate a re-evaluation of this opinion.

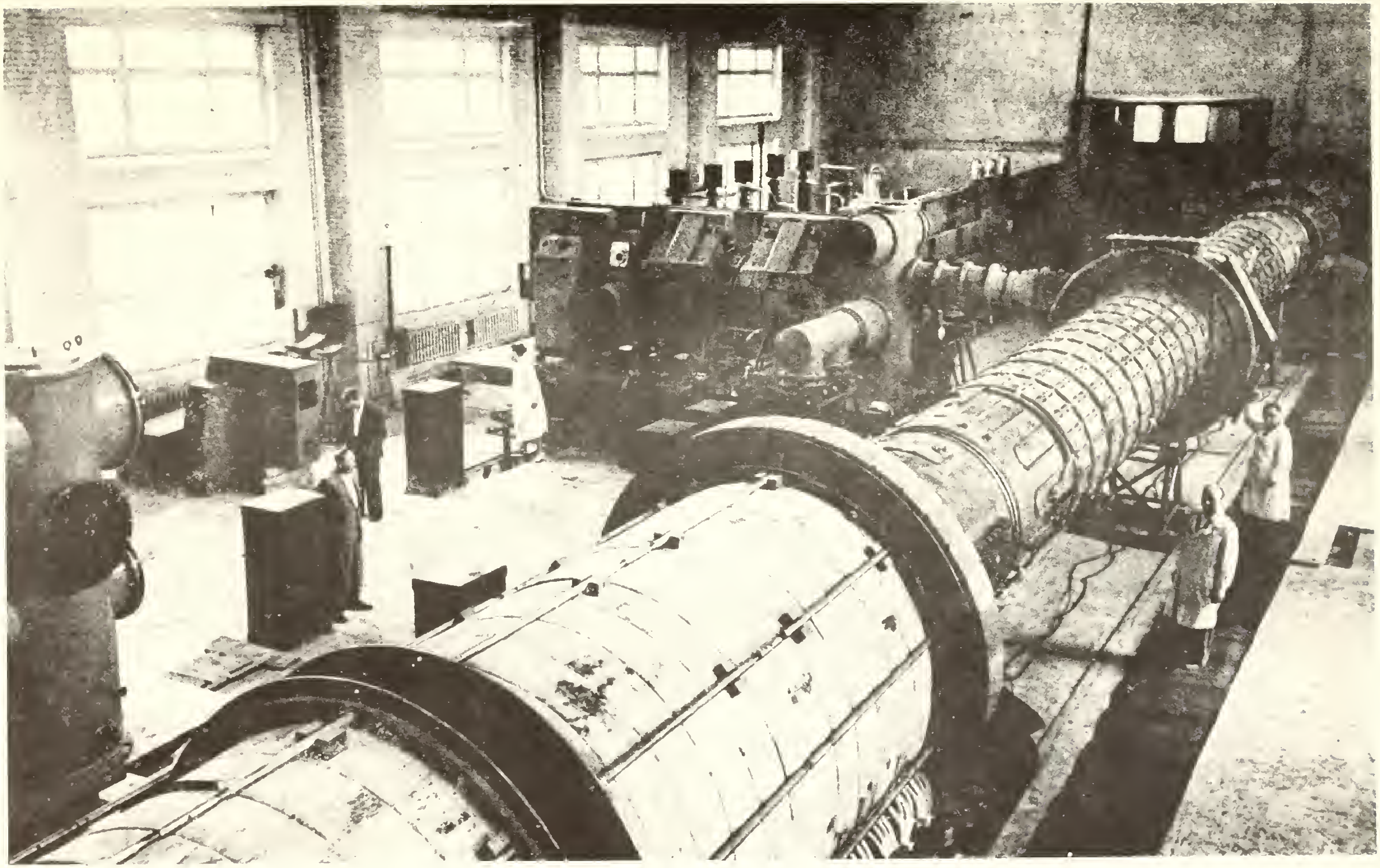


FIGURE 5. Ogra: a Soviet controlled thermonuclear research machine (adiabiatic trap machine).

CENTERS OF CONTROLLED THERMONUCLEAR RESEARCH

The Soviets have never revealed all centers of thermonuclear research within the Soviet Union. However, the following institutes have been positively identified as conducting or planning controlled fusion research:

1. Institute of Atomic Energy, Academy of Sciences, USSR, Moscow
2. Leningrad Physico-Technical Institute, Leningrad
3. Electro-Technical Institute, Leningrad
4. Ukrainian Physico-Technical Institute, Khar'kov
5. Sukhumi; Institute of Electronic Physics, Sukhumi
6. Institute of Physics, Siberian Department, Academy of Sciences, USSR, Novosibirsk

In addition to these six institutes, it is highly probable that the major Soviet universities are participating in general fusion research. This is especially true of Moscow State University in view of its close association with the Institute of Atomic Energy.

Institute of Atomic Energy (IAE), Academy of Sciences, USSR, Moscow

This institute is the chief center of controlled fusion research in the Soviet Union. Most of the controlled fusion research reports presented by Soviets at Geneva II were reports of work done at the IAE. All of the papers contained in the four volume presentation set, supposedly were reports of research conducted at the IAE. It was at this institute that Artsimovich and Leontovich conducted the initial research upon which Kurchatov based his speech at Harwell, England, in April 1956.

OGRA, a major Soviet fusion research device announced at Geneva II, as well as its prototype, OGRINA, is located at this institute.

Igor' V. Kurchatov is the administrative director of this institute. L. A. Artsimovich is the technical director of the fusion research program at IAE and M. A. Leontovich is responsible for theoretical support to this program.

Although the total number of personnel involved in this fusion research project is unknown, the basic organization of the group is shown in the accompanying table. The information contained in this table was given by the Soviets to Western scientists who visited the laboratory.

Leningrad Physico-Technical Institute (LPTI), Academy of Sciences, USSR, Leningrad

S. E. Frish, a scientist known to be associated with the Leningrad Physico-Technical Institute presented a paper on diagnostic measurements of gaseous discharges at the Venice Conference. The paper in itself was not too significant by Western standards, but Frish displayed a considerable knowledge of controlled thermonuclear research problems and techniques. He showed an intense interest in Western papers pertinent to this problem and his questions were those of a man well informed on the subject.

None of the Soviet fusion papers presented at Geneva II seemed to cover any research at LPTI. However, later information indicated that scientists from this institute were participating in research involving ALPHA, the large toroidal apparatus reported by the Soviets and reportedly located in Leningrad.

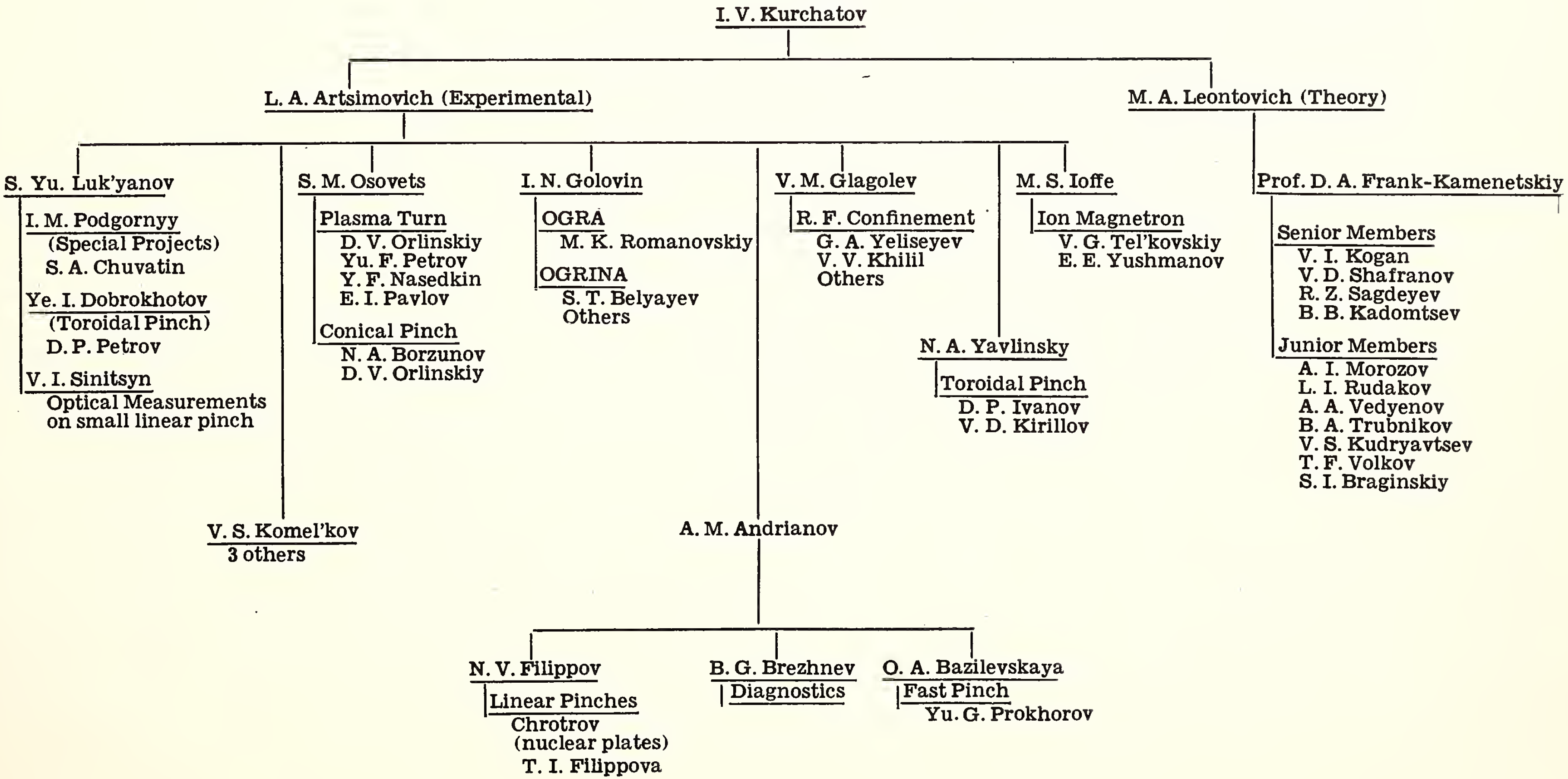
A. P. Komar has been reported as being the director of the Leningrad Physico-Technical Institute.

Electro-Technical Institute, Leningrad

This institute has been reported as the location of the Soviet fusion research apparatus ALPHA, a toroidal apparatus. There is doubt as to the accuracy of the identification of the institute connected with the ALPHA. Its director has been identified as Komar. The director of the Leningrad Physico-Technical Institute is Prof. A. P. Komar; and Ye. G. Komar has been identified as the director of the Institute of Electro-Physical Apparatus. The

TABLE

ORGANIZATION OF THE CONTROLLED THERMONUCLEAR RESEARCH EFFORT, INSTITUTE OF ATOMIC ENERGY



- I. V. Kurchatov
  - L. A. Artsimovich (Experimental)
    - S. Yu. Luk'yanov
      - I. M. Podgornyy (Special Projects)
        - S. A. Chuvatin
      - Ye. I. Dobrokhotov (Toroidal Pinch)
        - D. P. Petrov
      - V. I. Sinitsyn
        - Optical Measurements on small linear pinch
    - V. S. Komel'kov
      - 3 others
    - S. M. Osovets
      - Plasma Turn
        - D. V. Orlinskiy
        - Yu. F. Petrov
        - Y. F. Nasedkin
        - E. I. Pavlov
      - Conical Pinch
        - N. A. Borzunov
        - D. V. Orlinskiy
    - I. N. Golovin
      - OGRA
        - M. K. Romanovskiy
      - OGRINA
        - S. T. Belyayev
        - Others
    - A. M. Andrianov
      - N. V. Filippov
        - Linear Pinches
          - Chrotrov (nuclear plates)
          - T. I. Filippova
      - B. G. Brezhnev
        - Diagnostics
      - O. A. Bazilevskaya
        - Fast Pinch
          - Yu. G. Prokhorov
    - V. M. Glagolev
      - R. F. Confinement
        - G. A. Yeliseyev
        - V. V. Khilil
        - Others
    - N. A. Yavlinsky
      - Toroidal Pinch
        - D. P. Ivanov
        - V. D. Kirillov
    - M. S. Ioffe
      - Ion Magnetron
        - V. G. Tel'kovskiy
        - E. E. Yushmanov
  - M. A. Leontovich (Theory)
    - Prof. D. A. Frank-Kamenetskiy
      - Senior Members
        - V. I. Kogan
        - V. D. Shafranov
        - R. Z. Sagdeyev
        - B. B. Kadomtsev
      - Junior Members
        - A. I. Morozov
        - L. I. Rudakov
        - A. A. Vedyenov
        - B. A. Trubnikov
        - V. S. Kudryavtsev
        - T. F. Volkov
        - S. I. Braginskiy

institute with which Ye. G. Komar is identified has been responsible for building large electrical equipment such as the 680-Mev accelerator which is now at Dubna. The statement that scientists from the Leningrad Physico-Technical Institute assisted scientists at the Electro-Technical Institute in research involving ALPHA, seem to indicate an institute apart from LPTI. The statement that the Electro-Technical Institute built ALPHA, OGRA, and the cyclotron now at Dubna, combined with the fact that the institute is apart from LPTI, would indicate that the institute referred to as the Electro-Technical Institute is actually the Institute of Electro-Physical Apparatus.

There have been no technical papers on fusion research identified as originating at this institute.

Ukrainian Physico-Technical Institute, Khar'kov

K. D. Sinel'nikov is the director of this institute and has the assistance of such able physicists as A. I. Akhiyezer and Ya. B. Faynberg. Akhiyezer was present at the Venice Conference, although he did not present a paper. He did, however, show considerable interest in all reports applicable to controlled thermonuclear research. He has published several articles on plasma behavior in magnetic fields, and this type of research could be directly applicable to controlled fusion investigations.

R. A. Demirkhanov indicated at the Geneva II Conference that the work at Khar'kov was essentially theoretical backup for other experimental projects throughout the Soviet Union. This has not been completely confirmed by other evidence. Two reports presented at Geneva II gave evidence of theoretical research on one hand and experimental research on the other. In any instance, the entire CTR group at the Ukrainian Physico-Technical Institute seem to be more concerned with basic plasma research and diagnostic techniques than with any other phase of controlled thermonuclear research.

Sukhumi Institute of Electronic Physics

This institute has been identified by L. A. Artsimovich, as participating in the Soviet controlled fusion research program. At the time of Geneva II, R. A. Demirkhanov, when questioned extensively, indicated that his laboratory was located at Sukhumi and named the director as Kvartskhava (possibly I. F. Kvartskhava, the director (in 1952) of a nuclear research institute at Sinop, just south of Sukhumi).

Demirkhanov indicated that he is working on a device similar to the stellarator. While talking with some of the American scientists working on the stellarator exhibit at Geneva, he asked their permission to incorporate some of the features of the stellarator into his own research device. This is the only indication of experimental stellarator type research within the Soviet Union.

Although the exact identity and location of the "Sukhumi Institute of Electronic Physics" is rather uncertain, it is of interest to note the following:

In 1945 the Soviets established two research institutes just south of Sukhumi, at Sinop and Agudzeri, and staffed them with a mixed group of Soviet and German nuclear scientists. These laboratories were concerned, in the early years of their existence, with the development of methods for uranium isotope separation; electromagnetically, centrifugally, and by means of various diffusion systems. The electromagnetic work was done at Sinop, the area nearest Sukhumi, and Demirkhanov worked here with Manfred von Ardenze, on ion source development. When the German nuclear scientists left the area in 1955, the Soviet scientists apparently continued to operate the laboratory. This is probably the institute to which Artsimovich and Demirkhanov were referring.

Institute of Physics, Siberian Department, Academy of Sciences, USSR, Novosibirsk

The Soviets have made many public announcements concerning the establishment of a "Scientific City" on the banks of the Ob

River, just south of the Siberian city of Novosibirsk. The state of completion of the construction is unknown, but portions were indicated as being near completion in late 1958.

This establishment is to be a rather large complex, made up of many institutes, one of which is to be the Institute of Physics.

The Soviets have repeatedly announced that many scientists are to be transferred to this new institute and that one of their chief occupations will be controlled fusion research. The nature and extent of the proposed research to be conducted at this institute cannot be determined at this time.

G. I. Budker reportedly has been selected as the first director of the Institute of Physics.

APPENDIX A

SOVIET SCIENTIFIC PERSONNEL ASSOCIATED WITH CONTROLLED FUSION RESEARCH

The following list consists of the names of persons logically assumed to be associated with the Soviet Controlled Thermonuclear Research program. This list was compiled on the basis of technical publications, scientific presentations and known associations. Wherever possible, institute affiliations are indicated. In some instances, however, this affiliation is not positive but is an assumption based upon associations with persons of known institute affiliations. In every instance, the affiliation is according to the most recent information.

Abbreviations

Acad. Sci. USSR - Academy of Sciences USSR
Dep. Dir. - Deputy Director
Dir. - Director
Div. - Division
Hd. - Head
id/w - identified with
Inst. - Institute
Mbr. - Member
Sci. Res. Inst. - Scientific Research Institute
Theor. - Theoretical
U. - University
UkSSR - Ukrainian SSR

AKHIYEZER, A. I. - Ukrainian Physico-Technical Institute, Acad. Sci. UkSSR, Kharkov, Khar'kov State University im A. M. Gorkiy, 1957

AKIMOV, Yu. K. - Mbr., Joint Institute of Nuclear Research, 1957

ANDRIANOV, Aleksandr Mikhaylovich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

ANTROPOV, G. M. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

ARETOV, G. N. - Institute of Atomic Energy, Acad. Sci. USSR, 1956

ARTSIMOVICH, Lev Andreyevich - Deputy Director, Institute of Atomic Energy, Acad. Sci. USSR, 1958

ASKAR'YAN, G. A. - Mbr., Physics Inst. im P. N. Lebedev, Acad. Sci. USSR, 1954-58

BABIKOV, V. V. - Institute of Atomic Energy, Acad. Sci. USSR, 1954-55

BALABANOV, Ye. M. - Physics Inst. im P. N. Lebedev, Acad. Sci. USSR, 1954-55

BAZAROV, I. P. - Moscow State Univ. im M. V. Lomonosov, 1950-57 (Chair Theoretical Physics, 1951-52

BAZHANOVA, A. E. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

BAZILEVSKAYA, Ol'ga Aleksandrovna - Institute of Atomic Energy, Acad. Sci. USSR, 1958

BELYAYEV, S. T. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

BERGNER, Yu. K.

BEZBACHENKO, A. L. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

BYKOV, G. A. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

BOGOLYUBOV, Nikolay Nikolayevich - Joint Institute of Nuclear Research - Dubna, Hd., Lab. Theor. Physics, 1958; Hd., Chair Statistical Physics and Mechanics, Moscow State University im. M. V. Lomonosov 1958; Hd., Theoretical Physics Div., Inst. Mathematics im. A. V. Steklov, Acad. Sci. USSR, 1958

BONDARENKO, V. V. - Nuclear Research Institute, Sukhumi, 1957

BORZUNOV, N. A. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

BRAGINSKIY, Staliy Iosifovich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

BREZHNEV, Boris Gavrilovich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

BUDKER, G. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1958; Dir., Inst. Physics, Siberian Dept., Acad. Sci. USSR, 1957-58

CHERNIKOV, N. A. - Joint Institute of Nuclear Research, Dubna, 1957

CHROTROV, - Institute of Atomic Energy, Acad. Sci. USSR, 1958

CHUVATIN, S. A. - Institute of Atomic Energy, Acad. Sci. USSR, 1957-58

DAVYDOV, B. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1951

DEMICHEV, V. F. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

DEMIRKHANOV, R. A. - Sukhumi Nuclear Research Institute, 1958; id/w Inst. Physical Problems im S. I. Vavilov, Acad. Sci. USSR, 1956

DENISOV, N. G. - Gor'kiy Physico-Technical Inst., 1951-56; Gor'kiy State University, 1957-58

DOBROKHOTOV, Ye. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

DUBOVOY, L. V. - Ukrainian Physico-Technical Institute, Acad. Sci. UkSSR, 1958

DUKEL'SKIY, V. M. - Mbr., Leningrad Physico-Technical Inst., Acad. Sci. USSR, 1948-57

DZHELEPOV, V. P. - Hd., Lab. Nuclear Problems, Joint Institute of Nuclear Research, Dubna, 1958

YEGOROV, V. S. - Sci. Res. Physics Inst., Leningrad State Univ. im. A. A. Zhdanov, 1956

FAYNBERG, Ya. B. - Ukrainian Physico-Technical Institute, Acad. Sci. UkSSR, 1957

FEDORENKO, N. V. - Leningrad Physico-Technical Inst., Acad. Sci. USSR, 1954-57

FEDORENKO, R. P. - Institute of Atomic Energy, Acad. Sci. USSR, 1957-58

FILIPPOV, Nikolay Vasil'yevich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

FILIPPOVA, T. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

FIRSOV, O. B. - Institute of Atomic Energy, Acad. Sci. USSR, 1957-58; Leningrad Physico-Tech. Inst., Acad. Sci. USSR, 1957

FLYAGIN, V. B. - Joint Institute of Nuclear Research, Dubna, 1957-58

FRANK-KAMENETSKIY, Prof. D. A. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

FRENKEL, I. I. - possibly I. I. FRENKEL, Central Sci. Res. Inst. of Technology and Machine Bldg, 1957

FRISH, S. E. - Leningrad Physico-Technical Institute, Acad. Sci. USSR, 1957-58; Sci. Res. Physics Inst. Leningrad State U. im A. A. Zhdanov, 1955-58

GALITSKIY, V. M. - Institute of Atomic Energy, Acad. Sci. USSR, 1951; id/w Moscow Engineering Physics Inst., 1957-58

GEL'FAND, I. M. - id/w Institute of Atomic Energy, Acad. Sci. USSR, 1957; Mbr., Moscow State U. im M. V. Lomonosov, 1958

GERSHMAN, B. N. - Gor'kiy State Univ. im N. I. Lobachevskiy 1955-57; Mbr., Gor'kiy Physico-Technical Inst., 1955

GINZBURG, V. L. - Physics Inst. im. P. N. Lebedev, Acad. Sci. USSR, 1942-57, (Mbr., Theoretical Physics Lab., 1945; Mbr., Sci. Council, 1950); Moscow State Univ. im M. V. Lomonosov, 1939-56 (Mbr., Optics Lab., Sci. Res. Inst. Physics 1939-40)

GLAGOLEV, V. M. - Institute of Atomic Energy, Acad. Sci. USSR, Moscow, 1958

GLOTOVA, G. I. - All-Union Electro-Technical Institute, Moscow

GOLANT, V. Ye.

GOL'DANSKIY, Vitaliy Iosifovich - Institute of Chemical Physics, Moscow, Acad. Sci. USSR; Physics Inst. im P. N. Lebedev, Acad. Sci. USSR, 1956-59

GOLOVIN, Igor' Nikolayevich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

GORBACHEV, V. M. - Leningrad State Univ. im A. A. Zhdanov, 1953-54

GORBATENKO, M. - Ukrainian Physico-Technical Institute, Khar'kov

GORDEYEV, G. V. - Leningrad State Univ. im A. A. Zhdanov - Leningrad; 1954 id/w Leningrad Physico-Tech. Inst., Acad. Sci. USSR, 1958

GRANOVSIY, V. L. - All-Union Electrical Engineering Inst. im V. I. Lenin, 1957

GUREVICH, A. V. - Physics Inst. im P. N. Lebedev, Acad. Sci. USSR, 1957

GUSEVA, L. G. - id/w All-Union Electrical Engineering Inst. im V. I. Lenin, 1956

GUVANOV, Ye. M. - Institute for Physical Problems im S. I. Vavilov, Acad. Sci. USSR; Physics Inst. im P. N. Lebedev, 1956

IOFFE, M. S. - Institute of Atomic Energy, Acad. Sci. USSR, Moscow, 1958

IONOV, N. I. - Leningrad Physico-Technical Institute, Acad. Sci. USSR, 1955-58

IORDANSKY, S. V.

ISAKOV, A. I. - Physics Institute im P. N. Lebedev, Acad. Sci. USSR, 1956-57

IVANENKO, D. D. - Moscow State University im M. V. Lomonosov, 1956-57; Physics Institute im P. N. Lebedev, Acad. Sci. USSR, 1958

IVANOV, D. P. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

KADOMTSEV, B. B. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

KAGAN, I. - Leningrad Physico-Technical Institute, Acad. Sci. USSR, 1957

KAGAN, Yu. M. - Leningrad State University - Leningrad, 1957; id/w Leningrad Inst. Precision Mechanics and Optics, 1957

KAZANTSEV, A. P. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

KHILIL, V. V. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

KHRABROV, V. A. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

KHVASCHEVSKIY, Ye. S. - id/w Inst. Physics & Math, Acad. Sci. Belorussian SSR and Belorussian State U. im V. I. Lenin, 1957

KIRILLOV, V. D. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

KIROCHKIN, U. - Ukrainian Physico-Technical Institute, Kharkov

KLIMONTOVICH, Yu. L. - Mbr., Moscow State U. im M. V. Lomonosov, 1956-58

KLIMOV, V. N. - Institute of Atomic Energy, Acad. Sci. USSR, 1951-52

KLYARFEL'D, B. N. - Prof., All-Union Electrical Engineering Inst. im V. I. Lenin, 1935-57 (Hd., Div. Electrical Discharges in Gases and Vapors of Metals, 1935-47)

KLYUCHAREV, A. P. - Ukrainian Physico-Technical Inst., Acad. Sci. UkSSR, 1956-57

KOGAN, Vladimir Il'ich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

KOLOMENSKIY, A. A. - Physics Institute im P. N. Lebedev, Acad. Sci. USSR, 1957

KOMEL'KOV, Vladmir Stepanovich - Institute of Atomic Energy, Moscow, 1958

KONYUKOV, M. V. - State Pedagogical Institute - Tula, 1957

KOROBEYNIKOV, V. P. - Math. Inst. im V. A. Steklov, Acad. Sci. USSR, 1957

KOSEVICH, A. M. - id/w Chernovitsy State U., 1956-57; id/w Ukrainian Physico-Tech Inst., Acad. Sci. USSR, 1957

KOVAL'SKIY, N. G.

KOZLOV, P. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

KUDRYAVTSEV, V. S. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

KULIKOVSKIY, A. G. - id/w Moscow State U. im M. V. Lomonosov, 1957-58

KURCHATOV, Igor'Vasil'yevich - Institute of Atomic Energy (Director), Acad. Sci. USSR, 1958

KURILKO, V. - Ukrainian Physico-Technical Institute, Kharkov

KVARTSKHAVA, I. F. - Dep. Dir., Nuclear Res. Inst., Sinop, Sukhumi, 1952-55; id/w Sukhumi Nuclear Res. Inst., 1957

LANDAU, L. D. - Hd., Dep. Theor. Physics, Inst. Physical Problems im S. I. Vavilov, Acad. Sci. USSR, 1957

LEBEDEV, S. V. - Physics Institute im P. N. Lebedev, Acad. Sci. USSR, 1957

LEONTOVICH, Mikhail Aleksandrovich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

LIFSHITS, Ye. M. - Mbr., Inst. Physical Problems im S. I. Vavilov, Acad. Sci. USSR, 1956-58

LUCHINA, A. A. - Moscow State U. im M. V. Lomonosov, 1955

LYUBARSKIY, G. Ya. - Ukrainian Physico-Technical Institute, Acad. Sci. UkSSR, 1958

LUK'YANOV, Stepan Yur'yevich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

LUN'KIN, Yu. P. - Leningrad Physico-Technical Institute, Acad. Sci. USSR, 1957

LUTSENKO, E. I. - Ukrainian Physico-Technical Institute, Acad. Sci. USSR, 1958

MANDEL'SHTAM, S. L. - Moscow - Physics Inst. im P. N. Lebedev, Acad. Sci. USSR, 1945-58 (Hd., Lab. Spectral Analysis 1945-51; Mbr., Sci. Council 1950; Hd., Dept. Spectroscopy 1956); Prof. Optics and Spectroscopy, Moscow Physical-Technical Inst., Moscow State Univ. im. M. V. Lomonosov, 1956

MELADZE, R. D. - id/w Sukhumi Nuclear Research Inst., 1956

MYAKISHEV, G. Ya. - Mbr., Chair Theor. Physics, Moscow State U. im M. V. Lomonosov, 1954-55

MIGDAL, A. B. - Institute of Atomic Energy, Acad. Sci. USSR, Moscow, 1956; id/w Moscow Engineering Physics Inst., 1958

MINTS, M. Ya. - Novosibirsk Pedagogical Inst., 1957

MISHIN, G. I. - Leningrad Physico-Technical Institute, Acad. Sci. USSR, 1957

MOROZOV, A. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1958; Mbr., Chair Statistical Physics and Mechanics, Moscow State U. im M. V. Lomonosov, 1957

MOROZOVA, T. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1954

MUKHOVATOV, V. S. - id/w Institute of Atomic Energy, Acad. Sci. USSR, 1958

NASEDKIN, Yu. F. - Institute of Atomic Energy, Acad. Sci. USSR, 1955-57

NEKRASHEVICH, A. M. - Ukrainian Physico-Technical Institute, Acad. Sci. USSR, 1958

NESTERIKHIN, Yu. E. - (id/w V. S. Komelkov, Yu. V. Skvortsov - collaborated on 1958 paper)

OGANESYAN, K. O. - Joint Institute of Nuclear Studies - Dubna, 1958

ORLINSKIY, D. V. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

OSOVETS, Samuil Markovich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

PARFENOV, D. S. - Institute of Atomic Energy, Acad. Sci. USSR, 1956

PAVLOV, E. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

PEREL', V. I. - Mbr., Karelo-Finnish State U., 1956; id/w Leningrad Inst. Precision Mechanics and Optics, 1958; id/w Sci. Res. Physics Inst., Leningrad State U. im A. A. Zhdanov, 1958

PETROV, D. P. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

PETROV, Yu. F. - Institute of Atomic Energy, Acad. Sci. USSR, 1955

PIS'MENNYY, V. D. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

PISTUNOVICH, V. I. - Institute of Atomic Energy, Acad. Sci. USSR, 195

PODGORNYY, Igor'Maksimovich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

POLIYEVKTOV-NIKOLADZE, N. M. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

POLOVIN, R. V. - Ukrainian Physico-Technical Institute, Acad. Sci. USSR Kharkov, 1957

PROKHOROV, Yu. G. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

RAYZER, Yu. P. - id/w Inst. Chem. Physics, Acad. Sci. USSR, 57/with Ya. B. Zeldovich

RAZUMOVA, K. A. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

ROGOV, Viktor Yakovlevich - Chief, Dept. of Quantum Physics, Irkutsk State Univ. im A. A. Zhdanov, Irkutsk, 1956-58

ROMANOVSKIY, M. K. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

RUDAKOV, L. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

RUMINA, K. P.

SAFRONOV, B. G. - Ukrainian Physico-Technical Institute, Acad. Sci. USSR, 1958

SAGDEYEV, R. Z. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

SAKHAROV, Andrey Dmitriyevich - Physics Institute im P. N. Lebedev, Acad. Sci. USSR, 1957

SAVOS'KIN, V. I. - All-Union Electro-Technical Institute, Moscow

SHCHEDRIN, N. I. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

SENA, L. A. - id/w Sci. Res. Inst. for Direct Current, 1956

SHAFRANOV, V. D. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

SHEPELEV, M. N. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

SHUKHTIN, A. M. - Mbr., Sci. Res. Inst. Physics, Leningrad State Univ. im A. A. Zhdanov, 1947-56

SHPIGEL, I. S. - Physics Inst. im P. N. Lebedev, Acad. Sci. USSR, 1956; id/w Electrophysical Lab., Joint Nuclear Res. Inst., Dubna, Kalinin Oblast', 1956

SILIN, V. P. - Physics Inst. im P. N. Lebedev, 1956-57

SIMEL'NIKOV, Kirill Dmitriyevich - Director, Ukrainian Physico-Technical Institute, Acad. Sci. UkSSR, 1958

SINITSYN, Vasiliy Ivanovich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

SITENKO, A. G. - Khar'kov State University im A. M. Gorkiy, Khar'kov, 1957; Ukrainian Physico-Tech. Inst., Acad. Sci. UkSSR, 1957

SKVORTSOV, Yu. V. - Physics Institute, im P. N. Lebedev, Acad. Sci. USSR, Moscow, 1957

SOKOLOV, A. A. - Possibly Sci. Res. Inst. Physics, Moscow State U. M. V. Lomonosov, 1957

SOLOV'YEV, L. S. - Institute of Atomic Energy, Acad. Sci. USSR, Moscow, 1957-58

STEPANOV, K. M. - Ukrainian Physico-Technical Inst., Acad. Sci. UkSSR, 1955-56-58

STRAKHOVSKIY, G. M. - Moscow State Univ. im M. V. Lomonosov, 1956-57

STRATONOVICH, R. L. - Moscow State Univ. im M. V. Lomonosov, 1956-57

STRELKOV, V. S. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

SULADZE, K. V. - id/w Sukhumi Nuclear Res. Inst., 1957

SYROVATSKIY, S. I. - Physics Institute im P. N. Lebedev, Acad. Sci. USSR, Moscow, 1956

TAMM, I. Ye. - Active Mbr., Acad. Sci. USSR; Mbr., Sci. Council, Joint Nuclear Res. Inst., 1957; Mbr., Physics Inst. im P. N. Lebedev, Acad. Sci. USSR, 1934-58 (Hd., Theoretical Physics Div. 1934-58; Mbr., Atomic Nucleus Lab. 1950; Mbr., Sci. Council 1950, Dir. 1946-53)

TAUBE, N. S. - id/w Sci. Res. Inst. for Direct Current, 1956

TEL'KOVSKIY, V. G. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

TERLETSKIY, Ya. P. - Moscow State University im M. V. Lomonosov, 1957

TIKHODEYEV, N. N. - Leningrad Polytechnical Inst. im M. I. Kalinin, 1953-55; id/w Sci. Res. Inst. for Direct Current, 1957-58

TIMOFEYEVA, G. G. - All-Union Electrical Engineering Inst. im V. I. Lenin, 1957

TOPOLYA, N. V. - Ukrainian Physico-Technical Institute, Kharkov, 1958

TRUBNIKOV, B. A. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

TSERKOVNIKOV, Yu. A. - Mathematics Institute im V. A. Steklov, Acad. Sci. USSR - Moscow, 1957

TUEZEK

VASADRIN - Institute of Atomic Energy, Moscow, 1958

VEDENOV, A. A. - Moscow State University im M. V. Lomonosov - Moscow, 1956; Institute of Atomic Energy, Acad. Sci. USSR, 1958

VOLKOV, T. F. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

YAVLINSKIY, Natan Aronovich - Institute of Atomic Energy, Acad. Sci. USSR, 1958

YAVORSKAYA, I. M. - Moscow State University im M. V. Lomonosov, 1957

YELISHEYEV, G. A. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

YUSHMANOV, E. E. - Institute of Atomic Energy, Acad. Sci. USSR, 1958

ZAYTSEV, A. A. - Moscow State Univ. im M. V. Lomonosov 1948-54 (Mbr., Physics Inst. 1948-52; Mbr., Chair Electron Optics and Oscillography, 1950-54)

ZAMYATNIN, Yu. S. - id/w V. M. Gorbachev, 1957 paper

ZAVGORODNOV, O. G. - Ukrainian Physico-Technical Institute, Acad. Sci. USSR, 1958

ZEYDLITS, P. M. - Ukrainian Physico-Technical Institute, Acad. Sci. UkSSR, 1956-58

ZEL'DOVICH, Ya. B. - Active Mbr., Acad. Sci. USSR, 1958, Inst. Chemical Physics, AS USSR, 1958

ZHARINOV, A. - Institute of Atomic Energy, Acad. Sci. USSR, 1957

ZIL'BERMAN, G. Ye. - Khar'kov State Univ. im A. M. Gor'kiy, 1955; id/w Leningrad Physico-Tech. Institute, AS USSR, 1958

ZUBAREV, D. N. - Institute of Atomic Energy, Acad. Sci. USSR, 1952; Inst. Mathematics im V. A. Steklov, AS USSR, 1957-58

APPENDIX B

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